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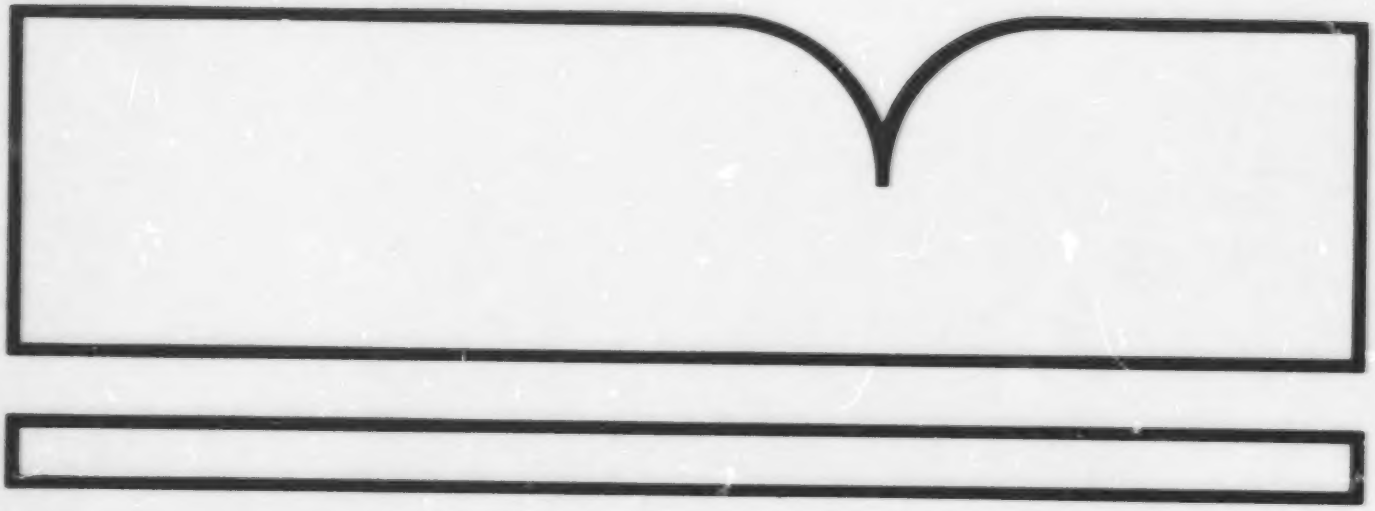

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VARIABILITY IN PATTERNS OF ACID DEPOSITION RESULTING FROM CLIMATOLOGICAL VARIABILITY

by

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16. ABSTRACT

Seasonal variability of sulfur wet deposition predictions have been assessed for a six-year period (1976-1981). From a 1980 SO_2 emissions data base and a 1976-1981 meteorological data base, the Advanced Statistical Trajectory Regional Air Pollution (ASTRAP) model produced 30 seasonal and annual sulfur wet deposition patterns and source-receptor matrices for North America. In addition, patterns of the coefficients of variation were also produced.

The annual wet deposition patterns were very similar with the maximum amounts predicted across eastern Ohio, western Pennsylvania and northern West Virginia. Variability of the seasonal patterns was more pronounced, especially for winter. The coefficients of variation were the smallest where the maximum depositions were predicted and greater in remote regions.

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Variability in Patterns of Acid Deposition Resulting from Climatological Variability

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The accuracy of model simulations of long range transport and deposition of acidifying substances has been a contentious matter in recent years, and in response, several extensive model development efforts have been launched. The models attempt to predict the atmospheric concentration and deposition patterns resulting from a given set of meteorological and emission conditions. The ultimate direct or indirect use of the models is in integrated assessments designed to evaluate various emission control options. As the science improves, the range of uncertainty in model predictions should decrease. However, since we cannot predict with certainty the climatology that particular future years will experience, there will be an irreducible uncertainty in deposition projections from that cause alone, regardless of how scientifically credible future models are perceived to be.

In previous work (Shannon, 1984) we examined climatological variability in modeling of long range transport and deposition, in particular the variability of source-receptor transfer matrices, a form of model output favored by policy analysts. At that time little more than two years of processed meteorological data (time series of precipitation and horizontal wind fields covering North America and adjacent waters) were available in a form suitable for use with the Advanced Statistical Trajectory Regional Air Pollution (ASTRAP) model (Shannon, 1981). More recently a six-year set (1976-1981) of analyzed meteorological data, the results of the first phase of a project that will examine a 22-year record (1960-1981) and perhaps more, has been produced and used in further investigations of climatological variability of deposition.

A brief description of ASTRAP is in order here. The ASTRAP model produces long-term, typically seasonally averaged atmospheric concentration fields and cumulative wet or dry deposition fields over scales of 100 km to continental distances for oxides of sulfur and nitrogen. Here we examine only oxides of sulfur. The ASTRAP model combines an emission inventory with statistics from a one-dimensional vertical integration and from two-dimensional horizontal dispersion calculations to produce the long-term results. The vertical integration varies dry deposition rates, linear chemical transformation rates, and vertical eddy diffusivity profiles diurnally and seasonally, and allows treatment of different effective plume heights, but is independent of horizontal location, and all meteorological variables are synthesized. Calculation of horizontal dispersion, on the other hand, requires time series of real meteorological fields, and results are a function of source location. From each virtual source at six-hour intervals simulated tracers are released, advected by the wind fields, and subjected to wet removal by the precipitation fields. Horizontal dispersion is estimated by fitting bivariant normal density functions to the trajectory endpoint ensembles as functions of plume age (time since release). The resulting overlapping puffs in effect form the long-term plume from each virtual source. Similar statistics are produced for wet deposited tracers; wet removal in ASTRAP is a function of the half-power of the six-hour precipitation total. Unless particular sources are being examined, emissions are usually described with a three-dimensional grid.

The meteorological data used in these simulations were analyzed at the University of Michigan and further processed at Argonne National Laboratory. The initial analyzed precipitation fields were hourly and 1/3 NMC scale (100-137 km in our regions of interest, increasing with latitude), while the initial wind fields were analyzed at 12-hour intervals on an NMC scale (300-381 km) for 500 m layers up to 3 km. Since the basic trajectory time step in ASTRAP is six hours, the hourly precipitation fields were summed over six-hour periods while the wind fields were temporally interpolated. For spring and summer, winds were averaged through the bottom three layers (1500 m transport layer), for winter the bottom two layers (1000 m transport layer), and for autumn the bottom 2.5 layers (1250 m transport layer). The meteorological fields were then organized in three-month meteorological seasons for each year, beginning in December. The only exceptions were the winter of 1976, since data for December 1975 were not yet analyzed, and the spring of 1978, as information for May 1978 was missing. In deposition simulations for those periods, a scaling factor of 1.5 was used.

In order to isolate climatological variability in deposition, emissions here have been held fixed except for seasonal variations. The inventory, a preliminary version developed as part of the National Acid Precipitation Assessment Program, is appropriate for 1980 anthropogenic emissions of sulfur dioxide and sulfate from the United States and Canada. Emissions have been gridded horizontally on a 1/3 NMC scale and vertically in 100 m layers to 400 m and in 200 m layers to 800 m.

Twenty-four seasonal patterns over the United States and Canada of both wet and dry deposition of total sulfur have been simulated. In addition, six annual deposition fields have been produced from addition of the appropriate seasonal fields. Isopleths of six-year average seasonal and annual deposition have also been generated,

along with standard deviations and coefficients of variation (standard deviation/mean).

Examination of the annual and seasonal wet deposition patterns for each year of meteorological data indicates that relative variability is greater when the temporal scale is shorter. The annual wet deposition patterns (Fig. 1) exhibit more similarities than dissimilarities, with the maxima always in the region encompassing eastern Ohio, western Pennsylvania, and northern West Virginia, and a general pattern oriented WSW-ENE with extensions toward groups of major point sources. The winter cases (Fig. 2) show more obvious yearly shifts than do other seasons (not shown); the winter with the greatest modeled wet deposition in New York and New England (1976) also has the least deposition in the Deep South. While relative variability is greatest during winter, absolute variability is least. Note that these simulations are not an attempt to simulate the actual deposition in any year except 1980, as the emission inventory is not varied annually.

Isopleths of statistics for the entire six years of meteorological data for both wet and dry annual deposition are shown in Figure 3. The average deposition patterns peak in the upper Ohio River Valley and are relatively high throughout the Ohio River Valley, the urbanized Northeast, and southeastern Ontario. The patterns of standard deviation of deposition show general similarity to the corresponding deposition patterns, except that the gradients of the former are flatter. For the patterns of coefficients of variation (CV), on the other hand, the field minima are located in roughly the same regions as the deposition maxima, while remote regions exhibit the largest CV. Relative variability is probably less in the major source regions because significant sources are located in many directions and thus there is less sensitivity to changes in transport direction, while in remote regions, particularly in the west, variations in the frequencies of trajectories from critical sectors become much more important. The CV of modeled wet deposition is about twice that of dry deposition in the Northeast. While both wet and dry deposition patterns can be shifted or stretched by variations in the transport processes, wet deposition is also directly affected by precipitation variations, while dry deposition is only indirectly affected (wet removal changes the mass available for potential later dry removal).

Seasonal wet deposition CV patterns are given in Figure 4. Relative variability is greatest during the winter, when most of the Northeast has a CV of 20 to 30%, and even larger values are found elsewhere. Because of the unusual winters of the last decade, winter deposition variability may prove to be greater here than in the complete 22-year period yet to be analyzed.

The same calculations that were made in producing the deposition isopleths have also been used to examine relative and absolute variability in source-receptor transfer matrices. In Table 1 some statistics of the five major contributors (as states) to wet deposition in two states containing sensitive receptor regions (the Adirondacks and the Boundary Waters) are given. As expected, the CV values for deposition in Minnesota, the state more remote from major source regions, are larger than those for deposition in New York. The variability of the absolute contribution from each source state shown is greater than the corresponding variability of that source state's percentage contribution to the deposition in all cases.

Table 1: ABSOLUTE AND RELATIVE CLIMATOLOGICAL VARIABILITY OF SELECTED WET SULFUR DEPOSITION SOURCE-RECEPTOR MATRIX ELEMENTS.

SOURCE-RECEPTOR	A	B	C	D
OH-NY	30.9	20.1	6	4
PA-NY	26.3	17.1	9	6
NY-NY	13.2	8.6	8	4
WV-NY	12.1	7.9	7	5
IN-NY	10.2	6.6	8	7
MN-MN	6.6	16.5	20	9
MO-MN	3.9	9.8	24	14
IA-MN	3.7	9.3	17	5
TX-MN	2.9	7.2	15	13
WI-MN	2.6	6.4	22	9

A: Mean annual absolute wet deposition contribution (kT S)
B: Mean annual relative wet deposition contribution (%)
C: Coefficient of variation (%) of absolute annual contribution
D: Coefficient of variation (%) of relative annual contribution

It is important to note that the climatological variability of deposition estimated here from simulations is that appropriate to subregional and larger spatial scales, and for seasonal or longer averages. Climatological variability on scales less than subregional, say 0-200 km, or on episodic temporal scales are not estimable with ASTRAP because of model resolution limitations. An individual monitoring station should observe more variability than these isopleths would indicate, particularly during convective precipitation regimes typical of summer.

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Shannon, J. D., 1981: A model of regional long-term average sulfur atmospheric pollution, surface removal, and net horizontal flux. Atmos. Environ. 15, 689-701.

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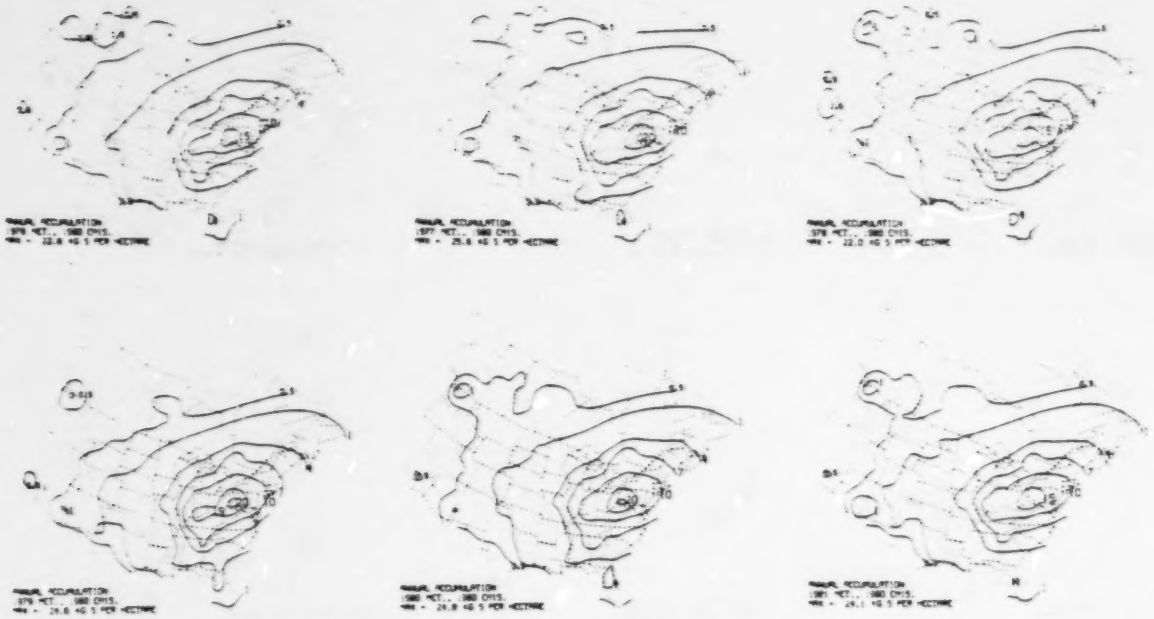

Figure 1: Annual wet sulfur deposition simulations (Kg S ha^{-1}) for 1980 emissions and meteorological data for each year of 1976-1981.

Figure 2: Winter wet sulfur deposition simulations (Kg S ha^{-1}) for fixed emissions and varied meteorology.

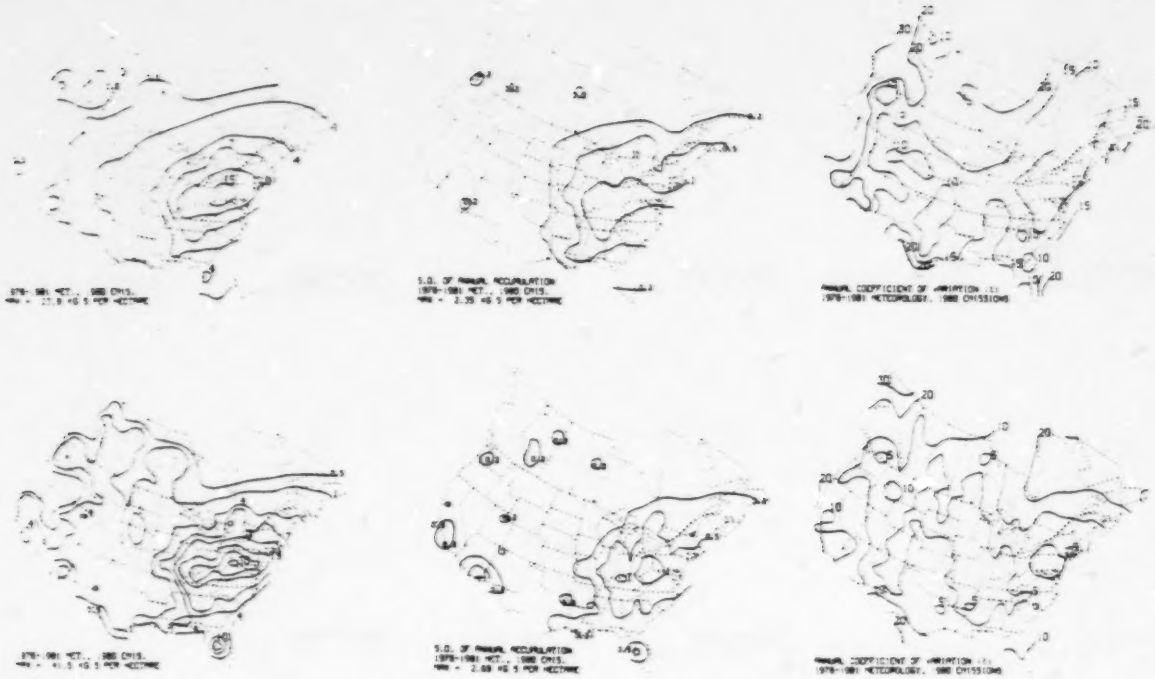

Figure 3: Mean (Kg S ha^{-1}), standard deviation (Kg S ha^{-1}), and coefficient of variation (%) of simulated wet (top) and dry (bottom) sulfur deposition for fixed emissions and varied meteorology.

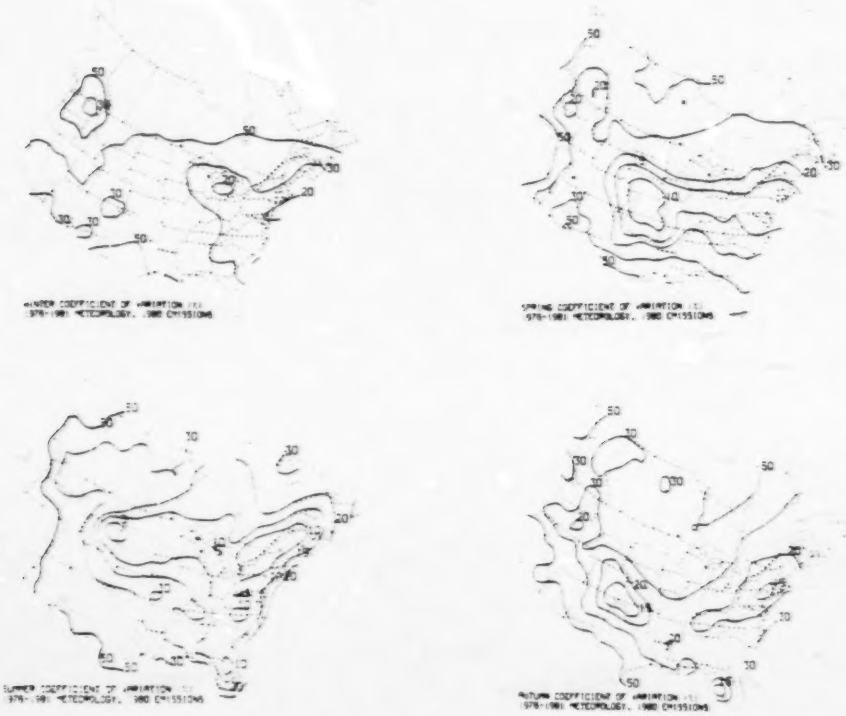

Figure 4: Seasonal coefficients of variation (%) of simulated wet sulfur deposition for fixed emissions and varied meteorology.

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